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ESTIMATION OF PEAK WINDS FROM HOURLY OBSERVATIONS

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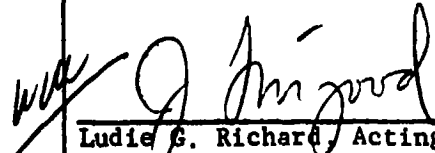
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16. ABSTRACT Two closely related methods to obtain estimates of the hourly peak wind at Cape Kennedy were compared by statistical tests. The methods evaluated the Monin-Obukhov stability length and the standard deviation of the hourly observed wind speed, so as to augment the latter quantity by F standard deviations. F is an optimized factor. A third method utilizing an optimized gust factor was also applied to the hourly wind. The latter procedure estimated 2952 peak winds with an rms error of 2.81 kt, an accuracy which was not surpassed by the other methods. The objective of this study was to develop peak ground wind speed data for use in Space Shuttle design and operation analyses.					
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FOREWORD

The work described in this memorandum was conducted by Northrop Services, Inc., Huntsville, Alabama, for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Aero-Astroynamics Laboratory, under Contract No. NAS8-21810, Appendix A, Schedule Order No. 7. Mr. S. Clark Brown was the Technical Coordinator for this task.

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Section I

INTRODUCTION

In Space Shuttle vehicle ground wind related analyses peak wind speeds are frequently more useful than the mean values found in the climatological records. Also, it is much easier to use peak speeds in the wind monitoring efforts that take place during the vehicle on-pad pre-launch activities.

Extracting peak values from original ground wind records was found to be very expensive, even when the data were readily available. To avoid the expense and to circumvent the missing data a search was undertaken to find a procedure whereby satisfactory estimates of hourly peak speeds could be obtained from standard observed hourly wind measurements which are archived with the National Climatic Center.

Wind gustiness characteristics at an anemometer site are largely determined by the roughness of the underlying terrain, the air mass stability, and the height of the instrument. In order to estimate hourly peak winds, recent turbulence and stability theory has been applied to hourly wind observations u , producing such quantities as the friction velocity u_{*0} , the Monin-Obukhov stability length L_0 , and the standard deviation of wind speed σ_u . These quantities lead to an estimate of peak wind u'_p , and there is an opportunity to optimize factor F in the final expression, $u'_p = u + F \sigma_u$.

To test the effectiveness of the theory on Cape Kennedy wind data, 2952 observations of u and u_p were selected from a set of 12 midseasonal hurricane-free months. As a control procedure, a simple optimized gust factor G was found from the same data sample and applied in the relation, $u'_p = Gu$. Then identical statistical evaluations were performed on peak wind estimates from all three procedures.

Section II

PROCEDURE

Two closely related methods were tested in the estimation of peak 10 m winds at Kennedy Spacecraft Center (KSC). The results of these tests on a 12-month sample were compared to a set of control statistics for the same sample.

The general procedure follows some suggestions made by Dr. George H. Fichtl, NASA, MSFC. In brief, the preliminary objective is to find a mixing length estimate - the Monin-Obukhov stability length - from consideration of the Pasquill stability class:

The solar radiation (I) is computed from the sun's hour angle (t), its declination angle (δ), its zenith angle (θ), and the latitude of KSC (ϕ) by equation 1,

$$I = [1.585 \cos \theta] [1 - 0.19 (\sec \theta)^{1/2}] \quad (1)$$

where

$$\cos \theta = \cos t \cos \delta \cos \phi + \sin \delta \sin \phi$$

The corrected solar radiation (I_c) is found from equation 2,

$$I_c = I(1 - 0.01 aC) \quad (2)$$

where

$$a = 0.3$$

c = cloud cover in percent.

This correction is insensitive to cloud type, the smallest possible transmission being 0.7. Since transmissions in dense low overcasts can be as small as 0.2, an attempt was made to take account of individual cloud type,

height, and amount. A search of the literature revealed nine reports in Russian which are not readily available and papers by Lumb (ref. 1) and Parker (ref. 2). Lumb's paper presents an empirical method of estimating total solar radiation, based upon data taken over the ocean at 52 1/2°N latitude, and Parker's paper does the same thing for an island station near the Equator. However, cloudiness at the former site is judged to be too unlike that at KSC to apply Lumb's formulae, and Parker has utilized certain data which are not contained in KSC surface reports. Therefore the parameter "a" has been held constant throughout a particular trial run.

The Pasquill stability class evaluation takes into account the 10-meter wind speed, the corrected solar radiation, and the nighttime cloud coverage. Table 2-1 and Figure 2-1, both from Pasquill (ref. 3), reveal six categories ranging from "extremely unstable" to "moderately stable". Examples of the utilization of a Pasquill stability classification may be found in estimates of plume dispersion, as by Turner (ref. 4).

Table 2-1. PASQUILL STABILITY CLASSES

A - Extremely unstable conditions D - Neutral conditions* B - Moderately unstable conditions E - Slightly stable conditions C - Slightly unstable conditions F - Moderately stable conditions					
SURFACE WIND SPEED, M/SEC	DAYTIME INSOLATION			NIGHTTIME CONDITIONS	
	STRONG	MODERATE	SLIGHT	THIN OVERCAST OR >4/8 CLOUDINESS†	<3/8 CLOUDINESS
<2	A	A-B	B		
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
>6	C	D	D	D	D
<i>*Applicable to heavy overcast, day or night</i> <i>†The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon which is covered by clouds.</i>					

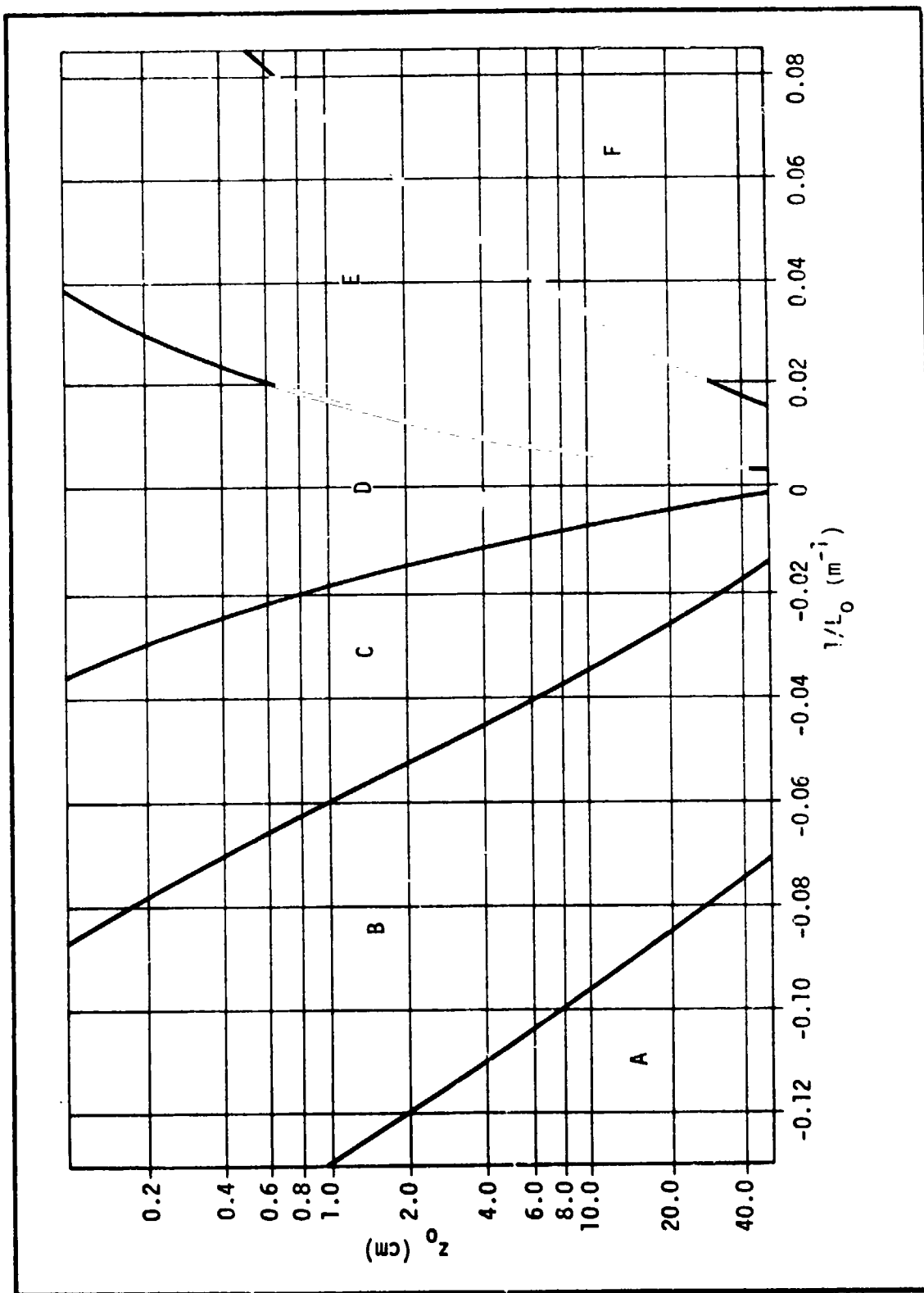


Figure 2-1. NOMOGRAM FOR CALCULATING L_0 FROM z_0 AND PASQUILL STABILITY CLASS

The Monin-Obukhov stability length L_o is then obtained by computerizing Table 2-1 and Figure 2-1. The roughness length z_o is assumed to be 0.2 m at KSC. The subsequent step marks the point of divergence for the two trial procedures and the control procedure, which will be designated A, B, and C, respectively.

Method A. The friction velocity u_{*o} is computed by equation 3, following Panofsky (ref. 5) and Paulson (ref. 6),

$$u_{*o} = ku / [\ln(z/z_o) - \psi(z/L_o)] \quad (3)$$

$$k = 0.4$$

u = hourly wind speed, an approximation to the mean wind speed over the 60-minute period of observation of peak winds

z/L_o = stability parameter

$$z = 10 \text{ m}$$

$$\text{If } z/L_o \begin{cases} < 0, x = (1 - 16z/L_o)^{1/4} \text{ and } \psi = \ln \frac{2z}{L_o} \frac{1+x}{1-x} \\ & - 2 \tan^{-1} \frac{z}{L_o} + \frac{\pi}{2} \\ = 0, \psi = 0 \\ > 0, \psi = - 5z/L_o . \end{cases}$$

Then the standard deviation of wind speed is estimated by equation 4,

$$\sigma_u = 2.5 u_{*o} . \quad (4)$$

Finally, the peak wind speed for a 60-minute period centered upon the hourly observation is estimated by equation 5,

$$u_p = u + F \sigma_u \quad (5)$$

F = factor to be optimized.

Method B. The friction velocity u_{*0} is computed as in Method A, but the limitation that $\sigma_u/u_{*0} = 2.5$ is removed by introducing a quantity $B(\psi, Ri, S)$ which was tested by Panofsky et al., (ref. 7).

Ri = Richardson number

S = stability parameter

$$B = Ri S^2 / \left[\ln \frac{z}{z_0} - \psi \frac{z}{L_0} \right]$$

$$\text{If } \frac{z}{L_0} \begin{cases} \leq 0, Ri = \frac{z}{L_0} \text{ and } S = 1 - 18 \frac{z}{L_0}^{-1/4} \\ > 0, Ri = \frac{z}{L_0} \left(1 + 5.2 \frac{z}{L_0} \right)^{-1} \text{ and } S = 1 + 5.2 \frac{z}{L_0} \end{cases}$$

as may be seen in Figure 2-2 (from reference 7), the ratio σ_u/σ_{*0} takes on the following values as B varies:

$$\sigma_u/u_{*0} = 2.75 \text{ when } 100 B < -0.175$$

$$\sigma_u/u_{*0} = 2.40 - 1.26 (100 B) \text{ when } -0.175 < 100 B < 0.254$$

$$\sigma_u/u_{*0} = 2.38 \text{ when } 100 B > 0.254 .$$

Equation 5 is again used to find u'_p .

Method C. The function $\psi(z/L_0)$ is set equal to zero except in the case where daytime insolation is strong and the hourly observed wind exceeds 6 m/sec. This implies that neutral conditions are assumed to exist in most of the cases.

In the computation of the peak wind, the value of u is multiplied by a gust factor G , where $G = 1 + 0.16 F'$ and F' is optimized. The expression for predicting u_p is then $u'_p = G u$.

In all of the above methods, the quantity u is really a short-period estimate of the mean wind through the 60-minute period for which peak wind speed is to be predicted.

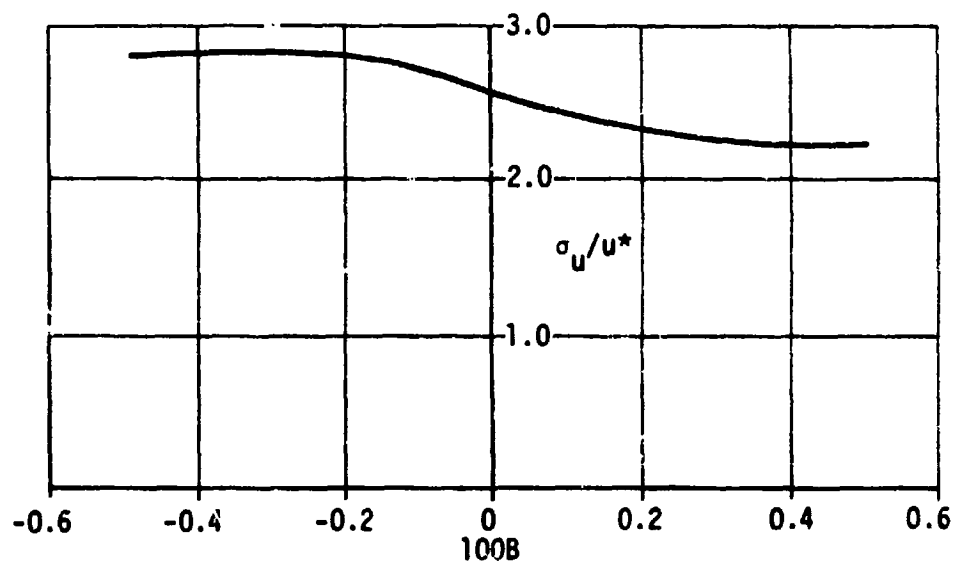


Figure 2-2. RATIO σ_u/u^* AS A FUNCTION OF B

Section III

DATA

The three methods were tested on three years of midseasonal months' data for Cape Kennedy, namely, January, 1966-1968; April, 1965-1967; July, 1965-1967; and October, 1965-1967. Eight reports per day at 01, 04, 07, 10, 13, 16, 19, and 22 EST were processed. There were no hurricanes in the vicinity of KSC during these months.

The recording anemometer providing the data for this study was a three-bladed Bendix-Friez installed at a height of 10 m. This anemometer had a threshold value of about 2.5 kt, so each recorded zero value of hourly wind speed was questioned. All zero values were finally replaced by an estimated average subthreshold value of 1.1 kt. In addition to these replacements, two obvious mistakes in data copying were corrected by interpolated values.

The distribution of the 2952 hourly observations of wind speed at Cape Kennedy is given in Figure 3-1. There is a skewed peak in the observations at 4 kt and no reported winds exceed 22 kt. A bias favoring even-numbered values over odd-numbered values is apparent over about half of the range, and it introduces an irregularity in the estimated peak winds which is permitted to remain.

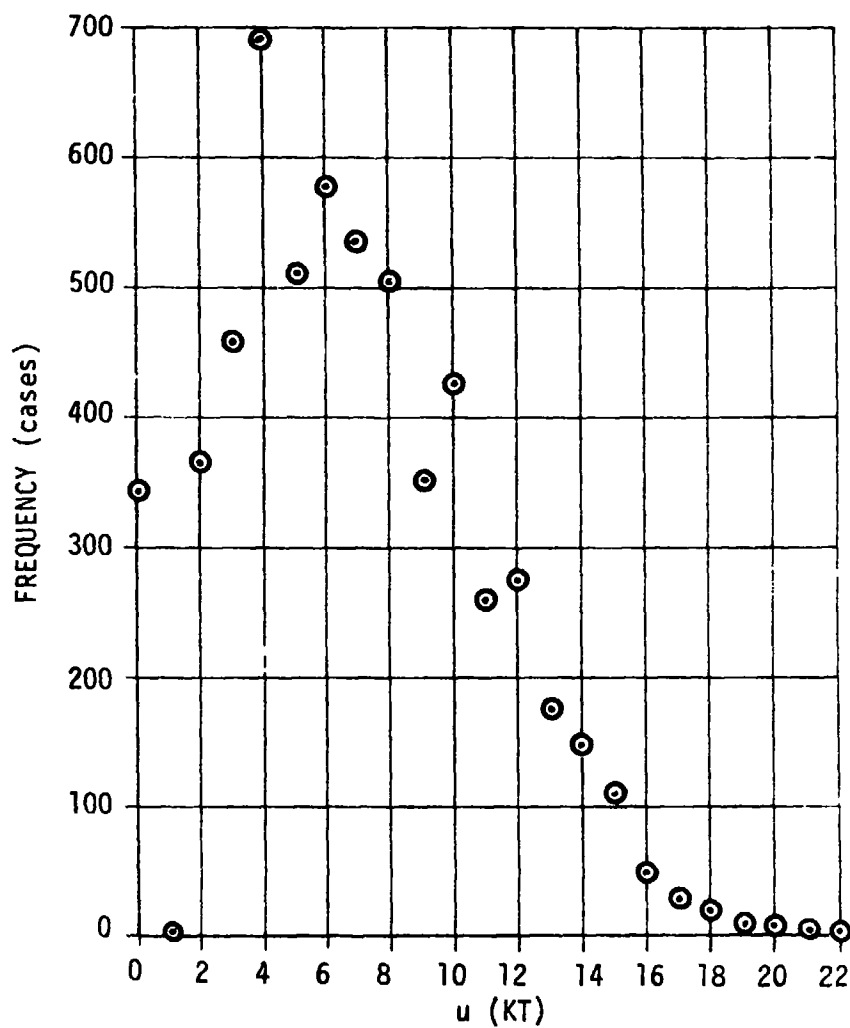


Figure 3-1. FREQUENCY DISTRIBUTION OF HOURLY WIND SPEED AT CAPE KENNEDY FOR JANUARY, APRIL, JULY, AND OCTOBER IN THE PERIOD FROM 1 APRIL 1965 TO 31 JANUARY 1968. ONLY HOURS 01, 04, 07, 10, 13, 16, 19, AND 22 EST ARE INCLUDED

Section IV

RESULTS

Taking all 12 months' data at a time, optimum F and F' factors were found from calculations of minimum rms errors. The outcome is shown in Figure 4-1, where F for Method A is 2.95, F for Method B is 2.7, F' for Method C (not shown) is 3.8. The spread of minimum rms error is but 0.34 kt, with the order of rank being C, A, B. The failure of Method B to surpass the other less complex methods indicates that Figure 2-2 may not be as representative of KSC as of the other sites to which it pertains.

The distributions of observed peak winds and estimates were placed on bar graphs (Figures 4-2, 4-3, 4-4). These figures all show a large surplus of estimates in the range 0.0 - 3.5 kt, a feature which may be attributed to anemometer inertia because this class contains all of the adjusted zero values mentioned in Section III.

For higher peak winds, each method has a notable excess in frequency somewhere within the 3.5 - 11.5 kt range. The excess for Method A is the least, and it occurs at 5.5 - 7.5 kt. The excess for Method C is the greatest, and it occurs at 9.5 - 11.5 kt. The excess for Method B is at 3.5 - 5.5 kt. All methods have notable deficits in frequency within the 10 - 15 kt range with another excess just under 20 kt.

The chi-square test is rendered inapplicable by the unevenness in the frequency distribution of observed peak wind speed, which is an empirical estimate of the true distribution of this quantity. However, as a tool for comparison of the three methods, chi-square values were computed. By this criterion, the order of rank (with chi-square values in parentheses) is A (288 kt), B (467 kt), C (610 kt).

Further testing was conducted by use of the Kolmogorov-Smirnov (K-S) test. The null hypothesis H_0 is, "for identical observational periods, there is no significant difference between the distributions of estimated peak wind

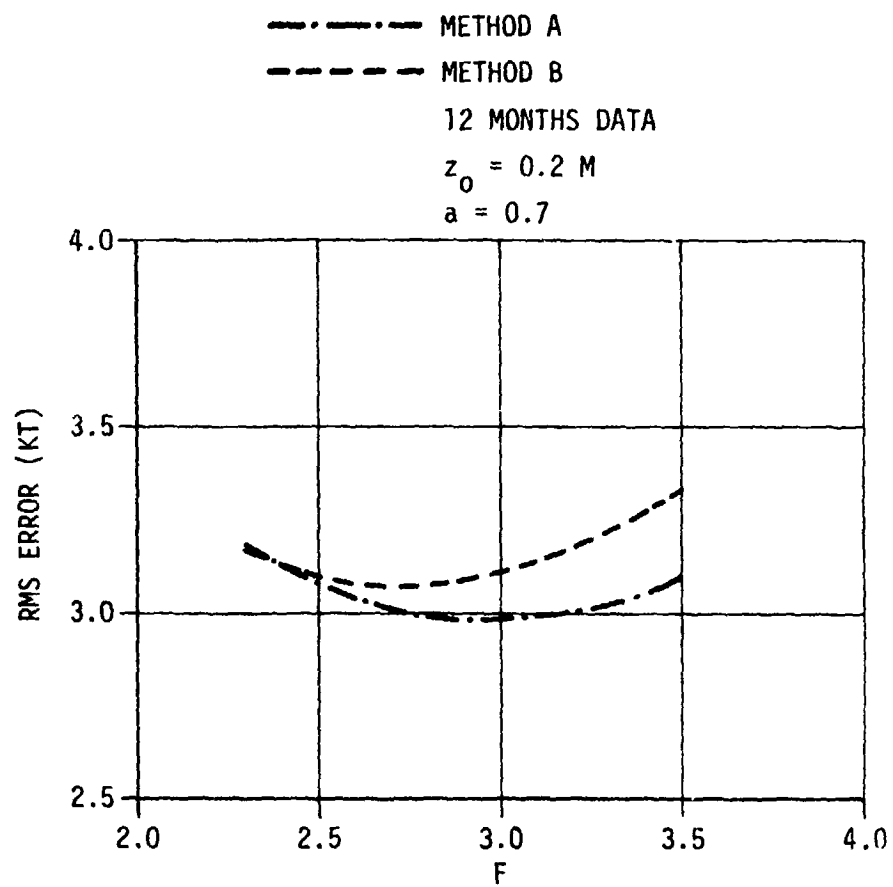


Figure 4-1. OPTIMIZATION CURVES FOR THE F-FACTOR OF METHODS A AND B

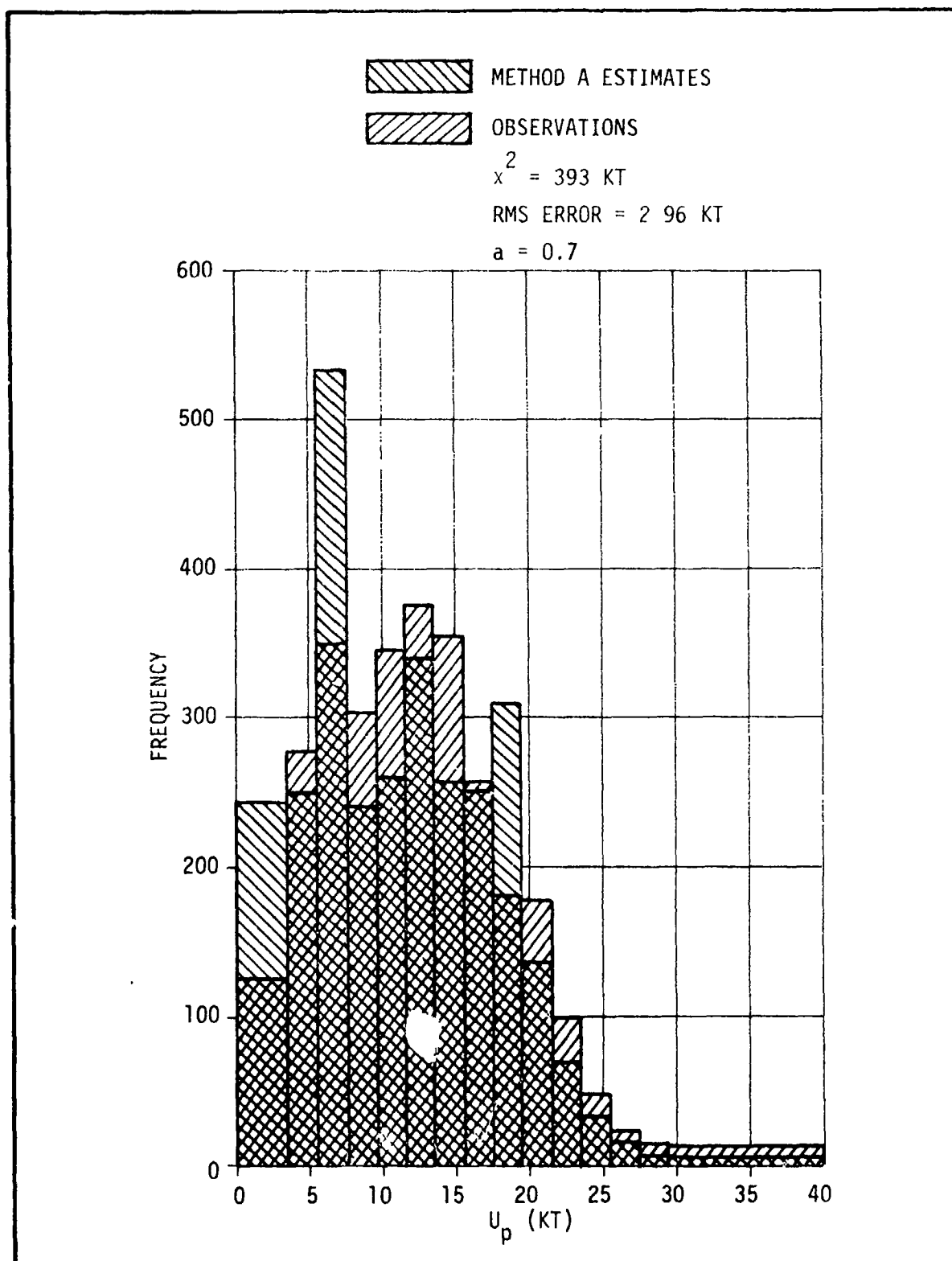


Figure 4-2. FREQUENCY DISTRIBUTION OF REPORTS OF PEAK WIND SPEED AND ESTIMATES OF PEAK WIND SPEED BY METHOD A. THE PERIOD IS AS NOTED IN FIGURE 3-1

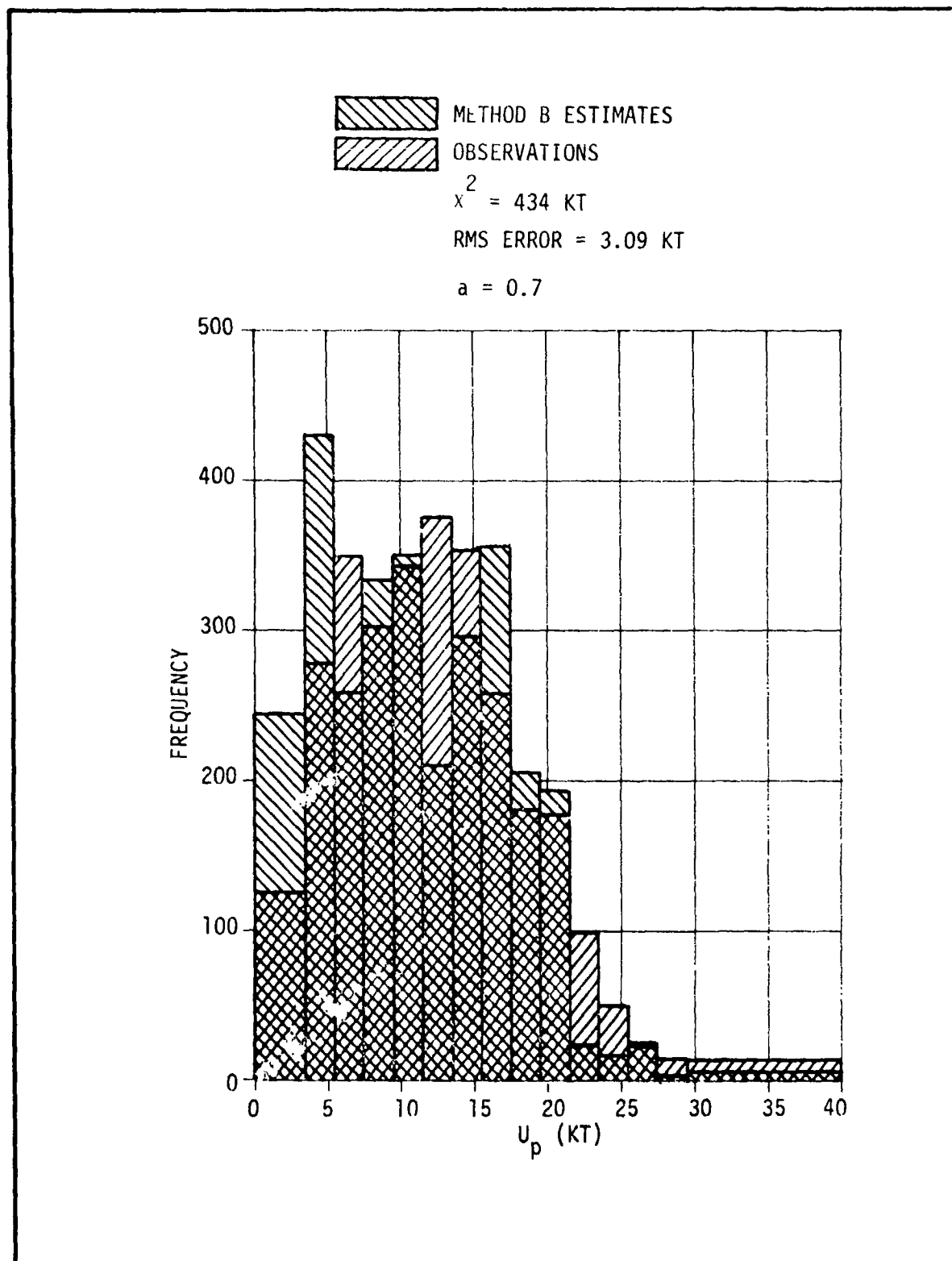


Figure 4-3. FREQUENCY DISTRIBUTION OF REPORTS OF PEAK WIND SPEED AND ESTIMATES OF PEAK WIND SPEED BY METHOD B. THE PERIOD IS AS NOTED IN FIGURE 3-1

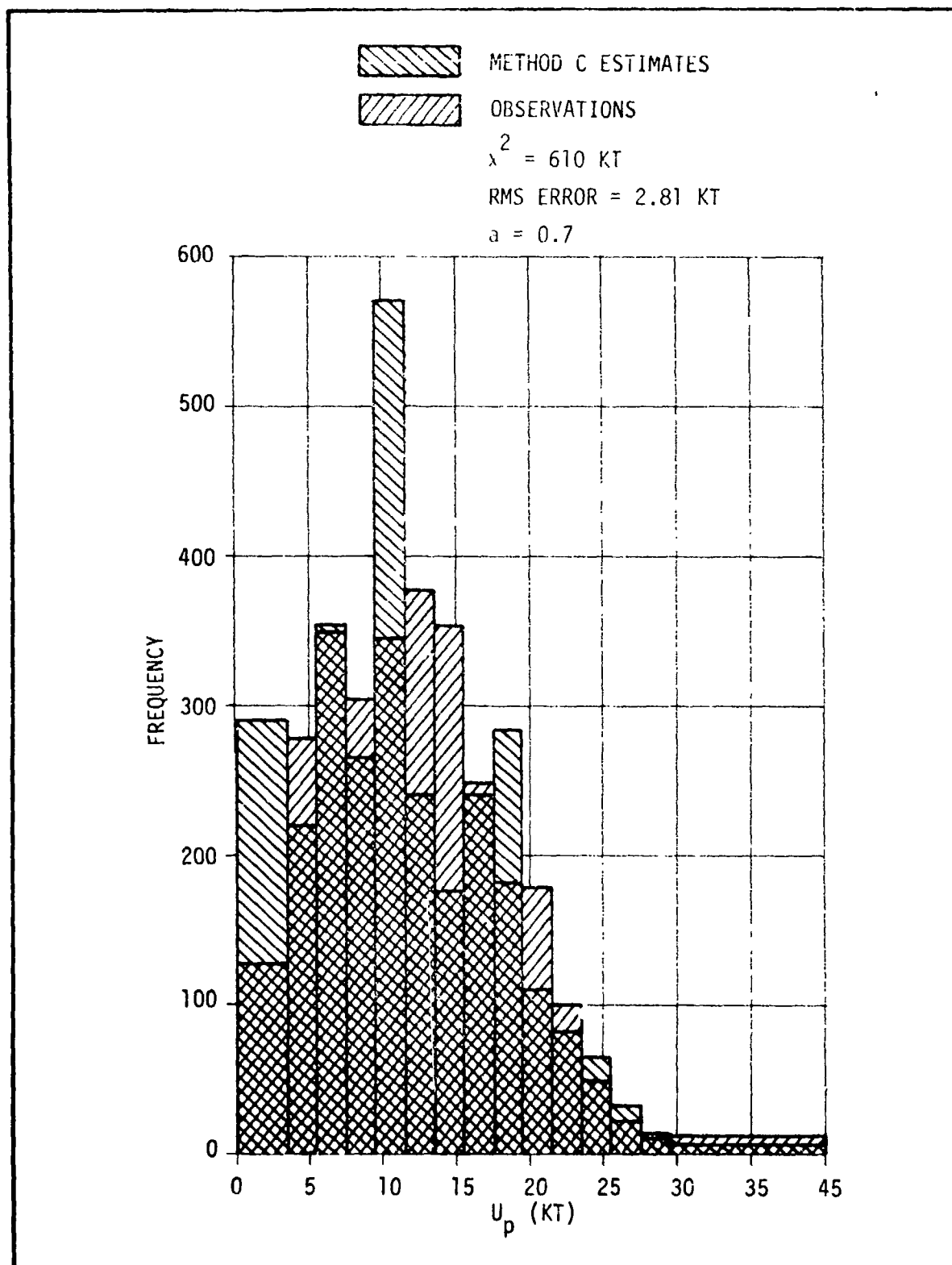


Figure 4-4. FREQUENCY DISTRIBUTION OF REPORTS OF PEAK WIND SPEED AND ESTIMATES OF PEAK WIND SPEED BY METHOD C. THE PERIOD IS AS NOTED IN FIGURE 3-1

speeds". Cumulative percent frequency (CPF) curves for the K-S test are given in Figure 4-5, and the results are listed in Table 4-1. According to tabulated critical values of the K-S statistic, H_0 need not be rejected at the five percent level nor the one percent level. The ranking of the three procedures by this criterion is A, C, B.

Table 4-1. KOLMOGOROV-SMIRNOV TEST VALUES FOR METHODS A, B, AND C

<u>A</u>	<u>N</u>	<u>B</u>	<u>N</u>	<u>C</u>	<u>N</u>
.086	14	.112	14	.103	14
N = number of degrees of freedom					

An additional comparison is available in a case by case tally of the most accurate method. This was carried on for the entire sample and for the subset of peak winds greater than 20 kt. Table 4-2 gives the outcome of the two counts, and it discloses an apparent superiority in Method C, the control procedure. This is especially evident in the subset of greater wind speeds, where Method C is best in 62.8 percent of the cases.

Table 4-2. RELATIVE ACCURACY OF ESTIMATES OF PEAK WIND SPEED BY METHODS A, B, AND C. I = INDETERMINATE, E.G., THE EDGE IN ACCURACY IS LESS THAN 0.1 KT.

	<u>METHOD</u>			
	<u>A</u>	<u>B</u>	<u>C</u>	<u>I</u>
All cases, frequency	261	622	1582	489
$u_p > 20$ kt, frequency	39	49	157	5
All cases, frequency (percent)	8.9	21.0	53.6	16.5
$u_p > 20$ kt, frequency (percent)	15.6	19.6	62.8	2.0

The correction factor, a , of equation 2 was also set equal to a greater value of 0.7 to test the sensitivity of the procedures. The overall result was a reduction of rms error of 0.05 kt and a small improvement in distribution of estimates. It is therefore concluded that 0.7 is a slightly more realistic correction factor than 0.3 at Cape Kennedy. When cloudiness reaches 100 percent, the transmission of insolation to the ground is then 30 percent and

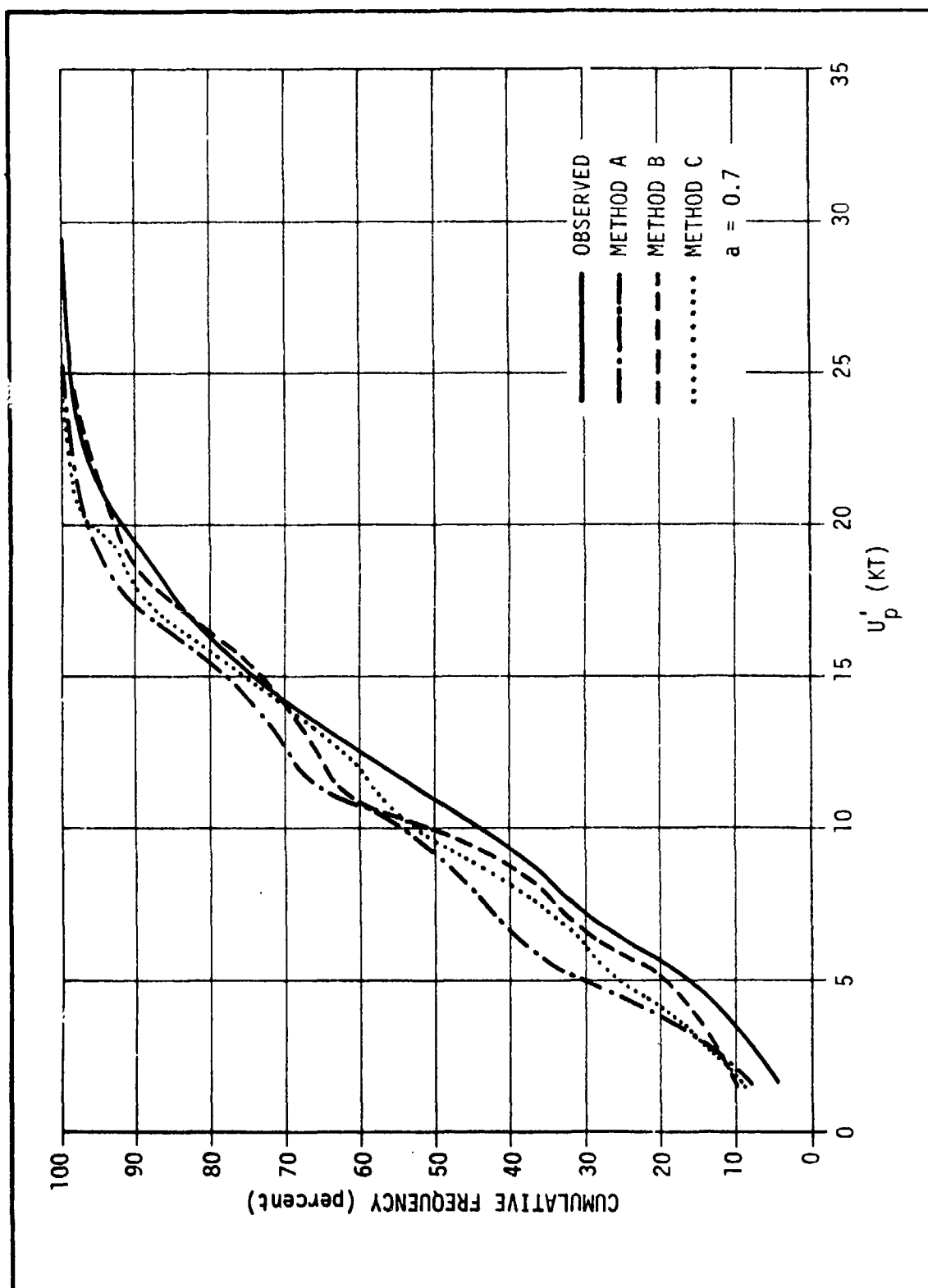


Figure 4-5. CUMULATIVE FREQUENCY CURVES FOR REPORTS OF PEAK WIND AND FOR ESTIMATES OF PEAK WIND BY METHODS A, B, AND C. THE DATA ARE AS NOTED IN FIGURE 3-1

the depletion is 70 percent. These values are generally representative of low stratified overcasts.

Individual estimates of peak wind are sensitive to the selection of the factor, a , in those infrequent cases when the Pasquill stability class (Table 2-1) is thereby changed. Crossing over a class boundary can vary the peak wind estimate by 10-15 percent.

Figure 4-6 gives a further comparison of the three methods, using the absolute error in peak wind as a criterion. The ranking is C, A, B, with this order being set in the 0-1 kt error class and continued throughout. The graph also discloses that about 30 percent of all cases are under 1 kt error, 80 percent are under 3 kt, and 95 percent are under 6 kt error.

Figure 4-7 uses percentage error in peak wind as a criterion, and it points up the lack of clear superiority of any method through the entire range of wind speeds. For example, at 5 kt, which includes observed hourly wind values from 3 to 7 kt, 90 percent of the cases of Method B are within 33 percent in accuracy, but this superiority does not hold through all of the percentile curves at 5 kt. Perhaps the most interesting feature of the three graphs is the dip in the control procedure, Method C, at 10 kt, which includes values from 8 to 12 kt, in the 90 percentile curve. Ninety percent of all cases in this category are under 20 percent error and this gives Method C its most notable advantage. However, the advantage is not retained at higher wind speeds.

The roughness length, z_0 , was changed from 0.2 m to 0.1 m to test the sensitivity of all procedures to this parameter. The results indicated little sensitivity at any point, that is, outcomes were practically identical to the previous runs.

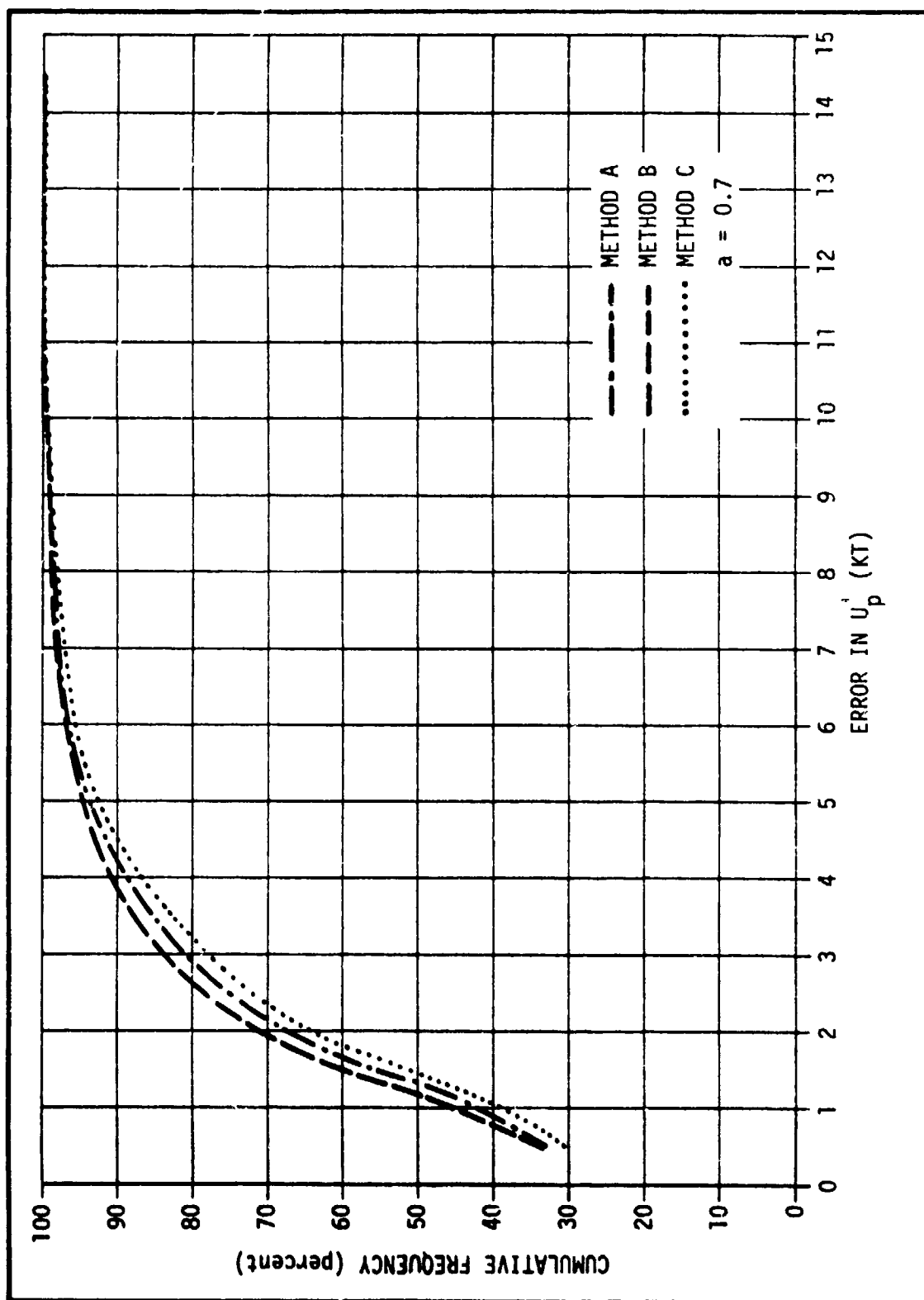


Figure 4-6. CUMULATIVE FREQUENCY CURVES FOR ABSOLUTE ERROR IN ESTIMATION OF PEAK WINDS BY METHODS A, B, AND C. THE DATA ARE AS NOTED IN FIGURE 3-1

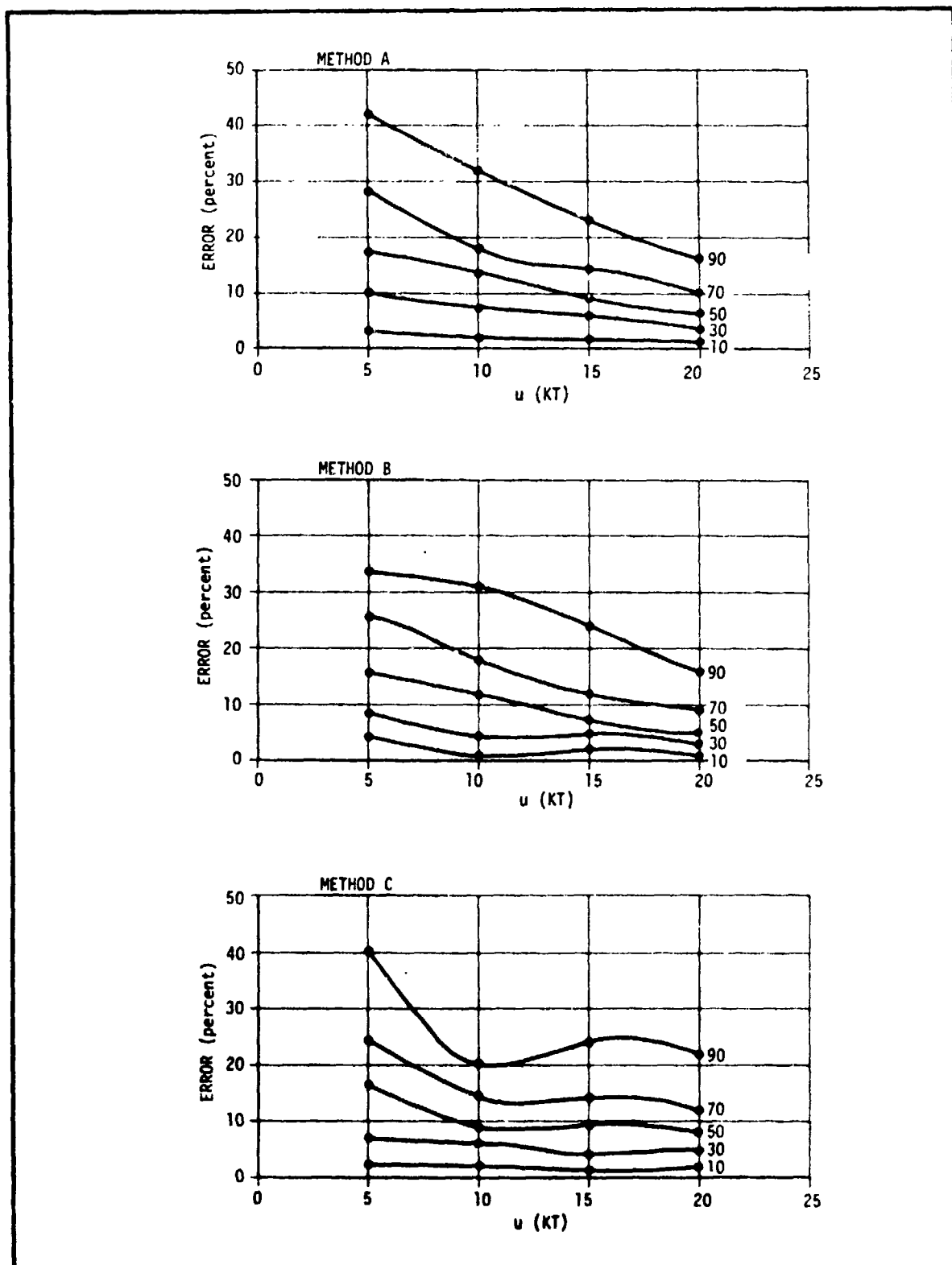


Figure 4-7. PERCENTILE CURVES FOR PERCENTAGE ERROR IN ESTIMATION OF PEAK WINDS BY METHODS A, B, AND C. THE PERCENTILE NUMBERS ARE AT THE RIGHT OF THE CURVES. THE DOTS REPRESENT A RANGE OF VALUES OF u FROM $u-2$ KT TO $u+2$ KT, INCLUSIVE

Section V

CONCLUSIONS

The advantages and disadvantages of the three evaluation schemes for peak wind are summarized in the following paragraphs.

Method A: $u_p' = u + 2.5 F u_{*0}$, where $u_{*0} = ku/(A-\psi(z/L_0))$.

The rms error is 3.01 kt over a 12-month data sample. The chi-square value is 288 kt, which is lowest. The K-S test value is also lowest. However, the tally of individual cases ranks this method below the others.

Method B: $u_p' = u + F \sigma_u$, where $\sigma_u = f(Ri, S, u_*)$.

The rms error of 3.15 kt is greatest. However, superiority over Method A is shown in Table 4-2.

Method C: $u_p' = Gu$

This is a control procedure in the sense that stability is largely ignored and a gust factor $G(=1.62)$ is simply applied to u to obtain u_p' . The rms error of 2.81 kt is smallest and this method ranks highest in the tally of individual cases and in Figure 4-7c for $8 \leq u \leq 12$ kt.

The control procedure using a gust factor yielded an rms error of less than 3 kt and it was not surpassed by either of two alternative schemes using the concepts of stability, the Monin-Obukhov mixing length, and the Richardson number.

Section VI

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